NASA TN D-200

NASA TN D-200

7N-20
197732
298

TECHNICAL NOTE

D-200

EXPERIMENTAL INVESTIGATION IN AN ALTITUDE TEST FACILITY OF BURNING OF EXCESS COMBUSTIBLES IN A ROCKET ENGINE EXHAUST

By Harry E. Bloomer, Paul E. Renas, and Robert J. Antl

Lewis Research Center
Cleveland, Ohio

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

WASHINGTON January 1960

(NASA-TN-D-200) EXPERIMENTAL INVESTIGATION IN AN ALTITUDE TEST FACILITY OF BURNING OF EXCESS COMBUSTIBLES IN A ROCKET ENGINE EXHAUST (NASA. Lewis Research Center) 29 p

N89-70743

Unclas
00/20 0197732

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

TECHNICAL NOTE D-200

EXPERIMENTAL INVESTIGATION IN AN ALTITUDE TEST FACILITY OF BURNING OF EXCESS COMBUSTIBLES IN A ROCKET ENGINE EXHAUST

By Harry E. Bloomer, Paul E. Renas, and Robert J. Antl

SUMMARY

An investigation was made in an altitude test chamber to determine methods of burning the excess fuel in the exhaust of a rocket engine. A 333-pound-thrust rocket engine, which used JP-4 fuel and gaseous oxygen as propellants was employed. Four afterburning configurations using bypass air as the oxidant and one using gaseous oxygen were tried. Gas samples were obtained from the rocket exhaust over the following ranges of variables: altitude pressure, 1 to 10 pounds per square inch; and rocket oxidant-fuel ratio, 1.80 to 3.20.

Results of the investigation show that combustibles can be burned over the range of variables covered, within a length of 38 rocket nozzle exit diameters. Burning these combustibles becomes easier as: (1) ambient pressure becomes higher, (2) excess air or oxygen (beyond air stoichiometric) is added, (3) more length is allowed for combustion, and/or (4) the air or oxygen is directed into the rocket exhaust rather than mixing unassisted.

INTRODUCTION

In the past, practically all rocket engine research has been conducted in static test cells or by actual firing of a vehicle. However, some phases of research require the use of closed altitude test facilities in which the exhaust gases are pumped to atmospheric pressure. Since maximum impulse for most propellants occurs with excess fuel mixtures (i.e., above stoichiometric), a question of safety arises because of the potentially explosive nature of the exhaust products.

Therefore, an investigation has been made in an altitude test chamber at the Lewis Research Center to determine methods by which the explosive potential of the exhaust gases could be eliminated. The methods investigated consisted of controlled burning of the excess fuel fraction as the exhaust gases were discharged from the rocket.

A 333-pound-thrust rocket engine which utilized JP-4 fuel and gaseous oxygen as propellants was used in the investigation in an attempt to burn the combustible products in the exhaust of the rocket. Four afterburner configurations using bypass air as the oxidant and one using gaseous oxygen were employed. Because in some installations an ejector with no secondary flow may be used to extend the altitude capabilities of test chambers, these same afterburner configurations were used behind a representative ejector. The ranges of conditions include a variation in altitude pressure from 10 to 1 pound per square inch corresponding to altitude variation from 10,000 to 60,000 feet. The oxidant-fuel ratio was varied from 1.80 to 3.20 (stoichiometric is 3.41) at a chamber pressure of approximately 200 pounds per square inch.

APPARATUS

Engine

A photograph of the rocket engine is presented in figure 1. The engine was run at a chamber pressure of 200 pounds per square inch and had a throat diameter of 1.20 inches. The exhaust nozzle had an area ratio of approximately 8.5 and an expansion half-angle of 15°. The engine was cooled by means of three spiral passages, which were manifolded at the nozzle exit and injector ends of the engine. The nozzle exit manifold was supplied with about 50 gallons per minute of water at high pressure, and the outlet manifold was drained to the sewer. The injector was made of copper and featured like-on-like impinging-jet orifices for the fuel and showerhead orifices for the gaseous oxygen. Fuel was supplied to the injector by means of high-pressure pumps. The gaseous oxygen was supplied from a large number of bottles which were manifolded together and were initially pressurized to 2300 pounds per square inch.

Facility

A schematic drawing of the rocket engine installed in the altitude test chamber is presented in figure 2. Altitude pressures were maintained by the facility exhaust system, while engine bypass air was supplied as required through the combustion air system. Five 2-foot-long water-cooled sections of pipe (18 in. in diam.) were used in the chamber that contained the rocket exhaust.

A water spray was used to further inert the exhaust gases after they were burned. For the no-secondary-flow ejector, a 6-inch-diameter water-cooled pipe, 4 feet long, formed the ejector tube. The rocket exhausted directly into this and thence into the 18-inch-diameter sections.

Rocket Exhaust Burning Configurations

The configurations employed to burn the exhaust gases are shown in figure 3. Configuration I (fig. 2) depended on mixing between the high-velocity rocket exhaust and the low-velocity secondary stream. Configuration II was designed to deflect the secondary stream into the rocket exhaust. Configurations III and IV were designed to inject air at sonic velocity normal to the direction of the rocket exhaust. Configuration V utilized oxygen instead of air as the secondary stream. When configurations I, II, and III were used with the rocket-ejector combination, the nomenclature was changed to IE, IIE, and IIIE, respectively. A photograph of configuration III is shown in figure 4.

Instrumentation

Transient instrumentation was provided so that rocket engine parameters could be monitored. Conventional manometer boards were used to measure pressures in the bypass air system and in the exhaust duct downstream of the rocket. Temperatures were measured on a flight recorder.

Sampling and analysis of the gases were accomplished in two ways. One method employed a helium leak detector working on the mass-spectrometer principle, which had been modified to detect the presence of hydrogen. The second method consisted of actually collecting samples in glass bottles (schematic drawing shown in fig. 5). The samples were then analyzed by laboratory techniques using gas chromatography apparatus. The samples were obtained from single total probes located on the centerline of the exhaust chamber pipe and from integrating total probes which had openings from the centerline to the inside surface of the pipe.

PROCEDURE

After proper altitude pressure and bypass airflow were set in the test facility, a time sequencing system was employed to control the events of the rocket firing automatically. An initial flow of gaseous hydrogen and oxygen was ignited by a torch located at the lip of the rocket exhaust nozzle. The main propellant flow was then introduced. One second before the termination of the firing, a solenoid tripped the camera which photographed the manometer boards and stopped the gas sampling process by actuating the pinchers (fig. 5).

The flight recorder, which measured temperature, was allowed to recycle during the firing time and was turned on and off manually. Some readings were manually recorded to provide a check on the transient data results.

RESULTS AND DISCUSSION

Basis for Interpretation of Sampling Results

The main exhaust products of JP-4 fuel and oxygen are carbon monoxide, carbon dioxide, water, and hydrogen, of which the only combustibles are hydrogen and carbon monoxide. Mixtures of air which contain more than 4 and less than 72 percent hydrogen by volume are flammable. Mixtures of air which contain more than 13.5 and less than 72 percent carbon monoxide by volume are flammable. These data have been obtained from reference 1.

The theoretical variation of the amounts of hydrogen and carbon monoxide in the rocket exhaust as a function of gas temperature and oxygen-fuel ratio is presented in figure 6. These results have been obtained from references 2 and 3. It should be noticed that the percent by volume of the combustibles for equilibrium expansion changes very little with temperature at low values of oxidant-fuel ratio (O/F). If frozen expansion is assumed, of course no variation occurs. The significance of this is that the sample composition could change only a few percent by the time it is analyzed.

Since the gas samples were collected in water-cooled total probes and allowed to stand at room temperature in sample bottles until analyzed, the composition reported was undoubtedly changed somewhat from the instantaneous values existing at the rocket nozzle exit, but would probably closely simulate the volume of combustibles in the cooled exhaust gases in a rocket test facility. Single total sample probes, located on the centerline of the exhaust chamber pipe, were used for the data presented in this report. Integrating-type probes were also employed, but the results were not consistent, since the outside unmixed layer of air diluted the combustibles in the sample at the station nearest the rocket nozzle exit more than at the extreme downstream station.

Sampling Results with Configurations I to V

Establishment of time constant for sampling systems. - Using the basic configuration (I), the length of rocket run required to purge the system and thereby obtain consistent sampling data was investigated. The results are presented in figure 7. The amounts of combustibles in percent by volume are presented as a function of rocket run time for the two sampling distance extremes. Rocket oxidant-fuel ratio, exhaust chamber pressure, and bypass air remained constant. The percent of combustibles in the samples became stabilized after run times of 25 seconds. Therefore, a run time of 28 seconds was standardized for the remainder of the investigation.

E-603

Effect of bypass airflow variation. - The variation of amount of combustibles in gas samples with bypass airflow using configuration I is presented in figure 8. Rocket oxidant-fuel ratio, ambient pressure in the exhaust chamber, and sampling distance were held constant. The bypass flow required to burn the exhaust products stoichiometrically is 3.12 pounds per second. This appears adequate to eliminate most of the combustibles. As expected, the amount of combustibles increases sharply as the bypass airflow is reduced below this amount.

Effect of exhaust chamber pressure variation. - The variation of the amount of combustibles in the exhaust samples with exhaust chamber pressure using configuration I is presented in figure 9. Rocket oxidant-fuel ratio and bypass airflow were held constant. Gas samples were collected at distances 6 and 10 feet downstream of the rocket exhaust nozzle. The amounts of combustibles increased as the exhaust chamber ambient pressure was lowered. The effects at 6 feet downstream of the rocket nozzle are much more pronounced that at 10 feet. More length is required to burn the combustibles at low pressure.

Effect of rocket oxidant-fuel ratio variation. - The variation of the amount of combustibles in the gas samples with rocket oxidant-fuel ratio is presented in figures 10(a) to (h). The amount of bypass airflow was varied with oxidant-fuel ratio to provide an air stoichiometric mixture with the excess fuel, and the exhaust chamber ambient pressure remained approximately constant at 2.4 pounds per square inch absolute. Percent excess fuel is defined as the unburned fuel in the propellant divided by the amount of fuel in the propellant at a stoichiometric mixture (and multiplied by 100). As the amounts of excess fuel increased, the amounts of combustibles in the gas samples became larger. As the distance of the sample probes behind the rocket nozzle became longer, the amounts of combustibles decreased.

Configurations II, III, and IV were designed to direct the bypass airflow (and configuration V, the oxygen) into the rocket exhaust to promote mixing and more efficient combustion and thereby decrease the amount of combustibles. Since these configurations added 1 foot to the length of the exhaust chamber and therefore to the sampling distances, the data for the original configuration must be interpolated in order to compare it with the others.

A comparison of the sampling results at the station 11 feet downstream would show no outstanding configuration, since very small amounts of combustibles exist. Therefore, 11 feet (which corresponds to 38 nozzle exit diameters) appears adequate to eliminate most of the combustibles. However, a comparison of the results at the station 7 feet downstream shows quite a difference in the performance of the configurations. For example, configuration I (fig. 10(a)) shows about 8.5 percent hydrogen and 16 percent carbon monoxide in the samples at the 7-foot station at 80 percent excess fuel. None of the other configurations show that much, and results for the radial-air-injection configuration (configuration III) are outstanding. Only 1 percent hydrogen and $2\frac{1}{2}$ percent carbon monoxide existed in those samples (fig. 10(c)).

The normal injection configuration (configuration V, using gaseous oxygen) shows that the same job can be done with only 23 percent of the air mass flow. With test facility exhauster capacity a primary consideration, this is an important point.

E-603

Results with No-Flow Ejector Attached to Rocket Exhaust Nozzle (Configurations IE to IIIE)

Figure 10(f) presents the results of the unassisted-secondary-air-mixing configuration (IE). The sampling stations 2 and 4 feet downstream of the rocket nozzle exit were eliminated by the ejector, and the other three stations were located 2, 4, and 6 feet downstream of the ejector exit.

It should be noted that the amounts of combustibles are higher than for the preceding configuations at the same distance downstream of the rocket nozzle exit because less mixing length is provided. The results from configurations IIE and IIIE are presented in figures 10(g) and (h). The dashed line interpolated for a distance of 6 feet downstream of the rocket nozzle exit enables direct comparison of the data. Again, the advantage to be gained by directing the bypass airflow into the rocket exhaust can be noted. The unassisted-mixing configuration (IE) shows about 3 percent hydrogen and 10 percent carbon monoxide in the samples at the station 6 feet downstream of the rocket nozzle exit at 80 percent excess fuel (fig. 10(f)). The air-deflection configuration (IIE) shows about 2 percent hydrogen and $7\frac{1}{2}$ percent carbon monoxide at this same condition (fig. 10(g)), while the radial-air-injection configuration (IIIE) shows only 1 and 5 percent, respectively (fig. 10(h)).

SUMMARY OF RESULTS

An investigation made in an altitude test chamber to determine methods of burning the excess fuel in the exhaust of a rocket engine yielded the following results:

1. Combustibles in a rocket exhaust can be burned (and explosive hazards eliminated) by adding sufficient air or oxygen to make a stoichiometric mixture with the excess fuel within the range of variables

covered by this investigation. The minimum ambient pressure investigated was 1 pound per square inch; the maximum length for burning provided in this investigation was approximately 38 rocket nozzle exit diameters. These conditions appear adequate for eliminating most of the combustibles.

2. The problem of burning these combustibles becomes easier as (1) ambient pressure becomes higher, (2) excess air or oxygen (beyond air stoichiometric) is added, (3) more length is allowed for combustion, and/or (4) the air or oxygen is directed into the rocket exhaust rather than mixing unassisted.

E-603

Lewis Research Center
National Aeronautics and Space Administration
Cleveland, Ohio, September 14, 1959

REFERENCES

1. Coward, H. F., and Jones, G. W.: Limits of Flammability of Gases and Vapors. Bull. 503, Bur. Mines, 1952.

2. Huff, Vearl N., and Fortini, Anthony: Theoretical Performance of JP-4 Fuel and Liquid Oxygen as a Rocket Propellant. I - Frozen Composition. NACA RM E56A27, 1956.

3. Huff, Vearl N., Fortini, Anthony, and Gordon, Sanford: Theoretical Performance of JP-4 Fuel and Liquid Oxygen as a Rocket Propellant. II - Equilibrium Composition. NACA RM E56D23, 1956.

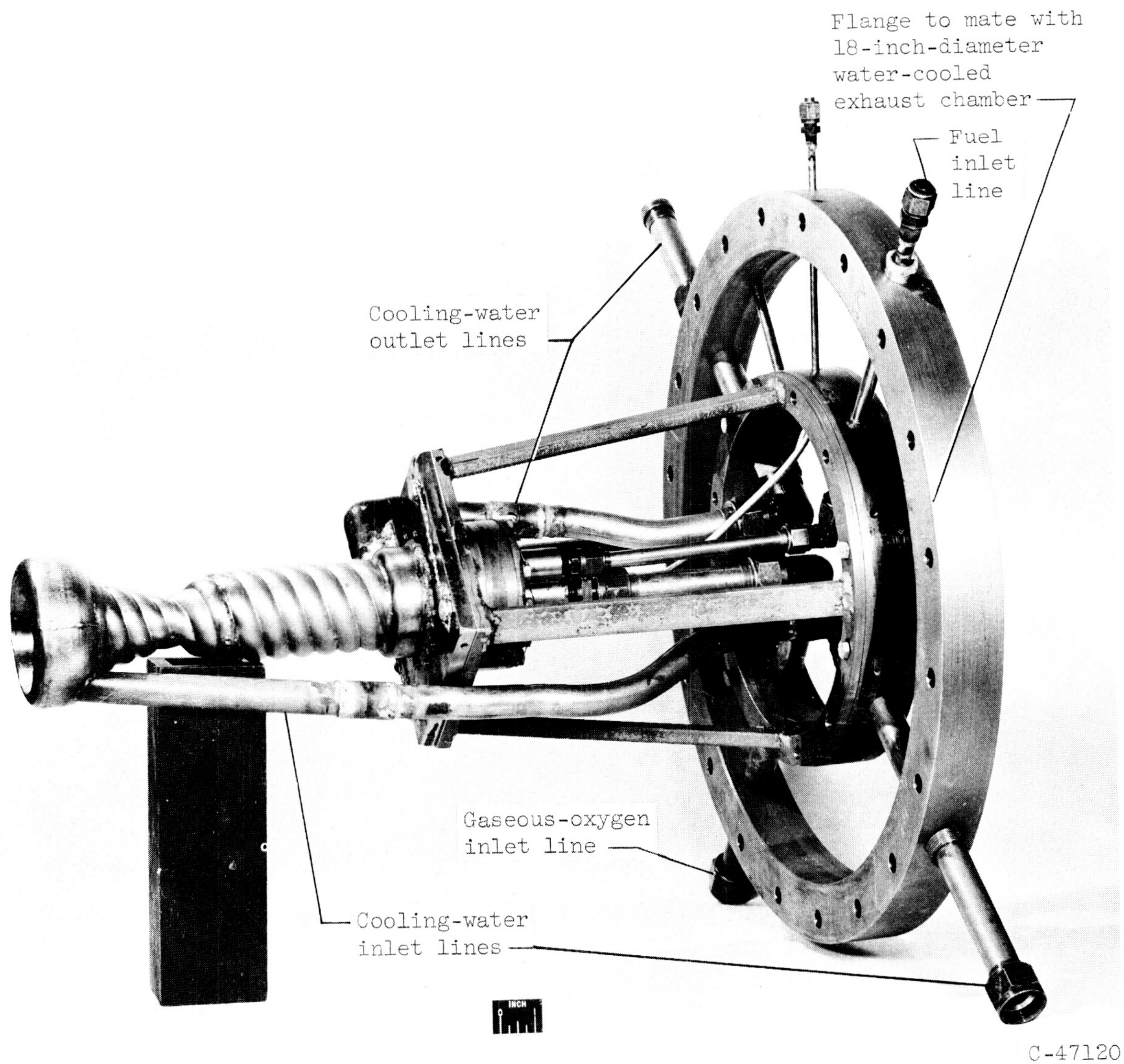


Figure 1. - View of rocket engine without enclosing shroud.

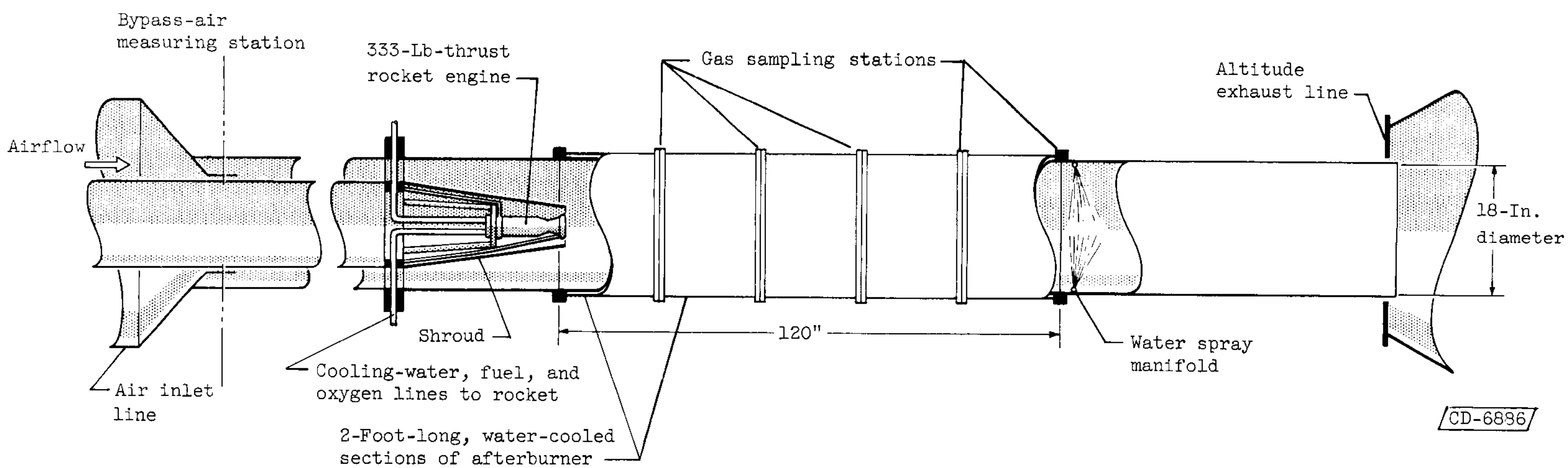
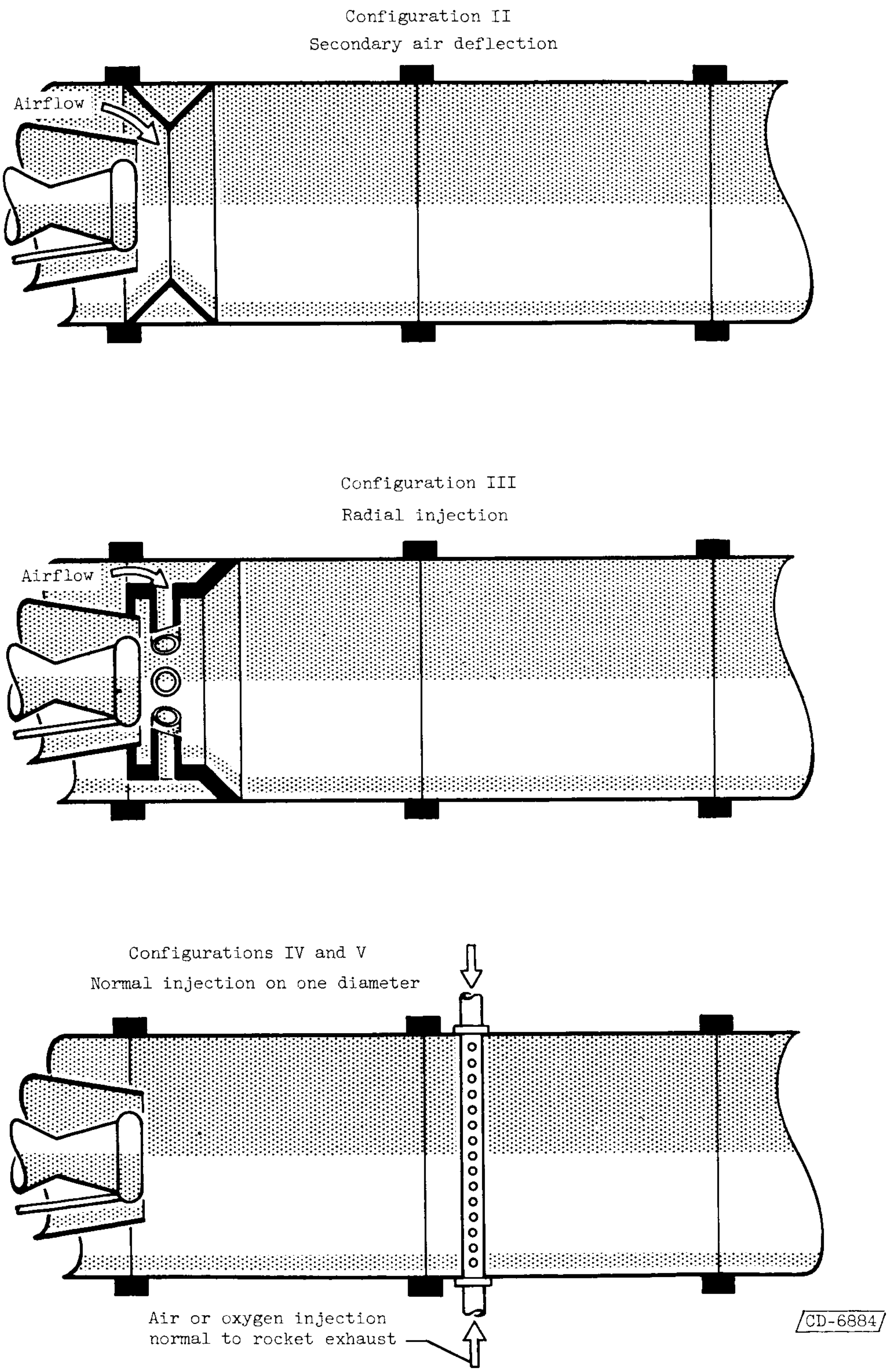


Figure 2. - Installation of rocket engine in test chamber showing afterburner configuration I. Unassisted secondary air mixing.



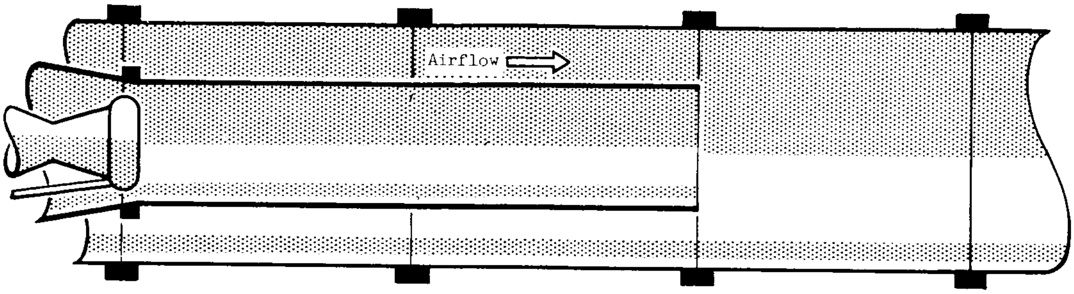
(a) Rocket discharging directly into exhaust duct.

Figure 3. - Afterburner configurations.

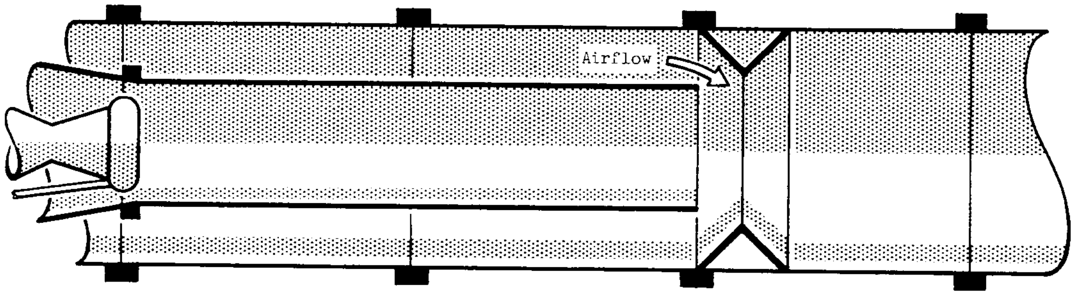
E-605

E-603

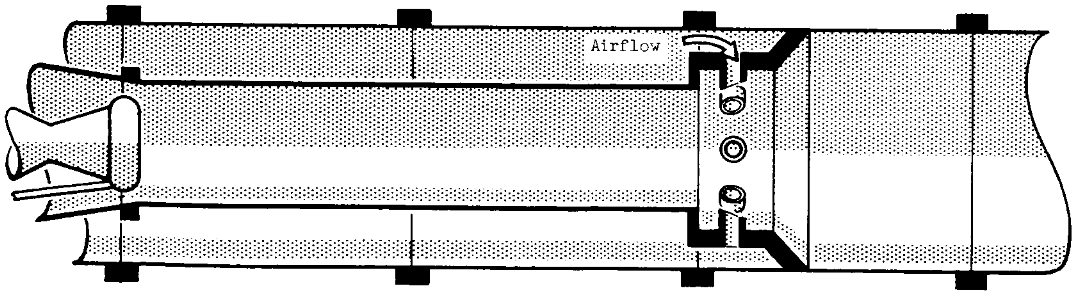
Configuration IE



Configuration IIE



Configuration IIIE



CD-6885

(b) Rocket discharging into ejector.

Figure 3. - Concluded. Afterburner configurations.

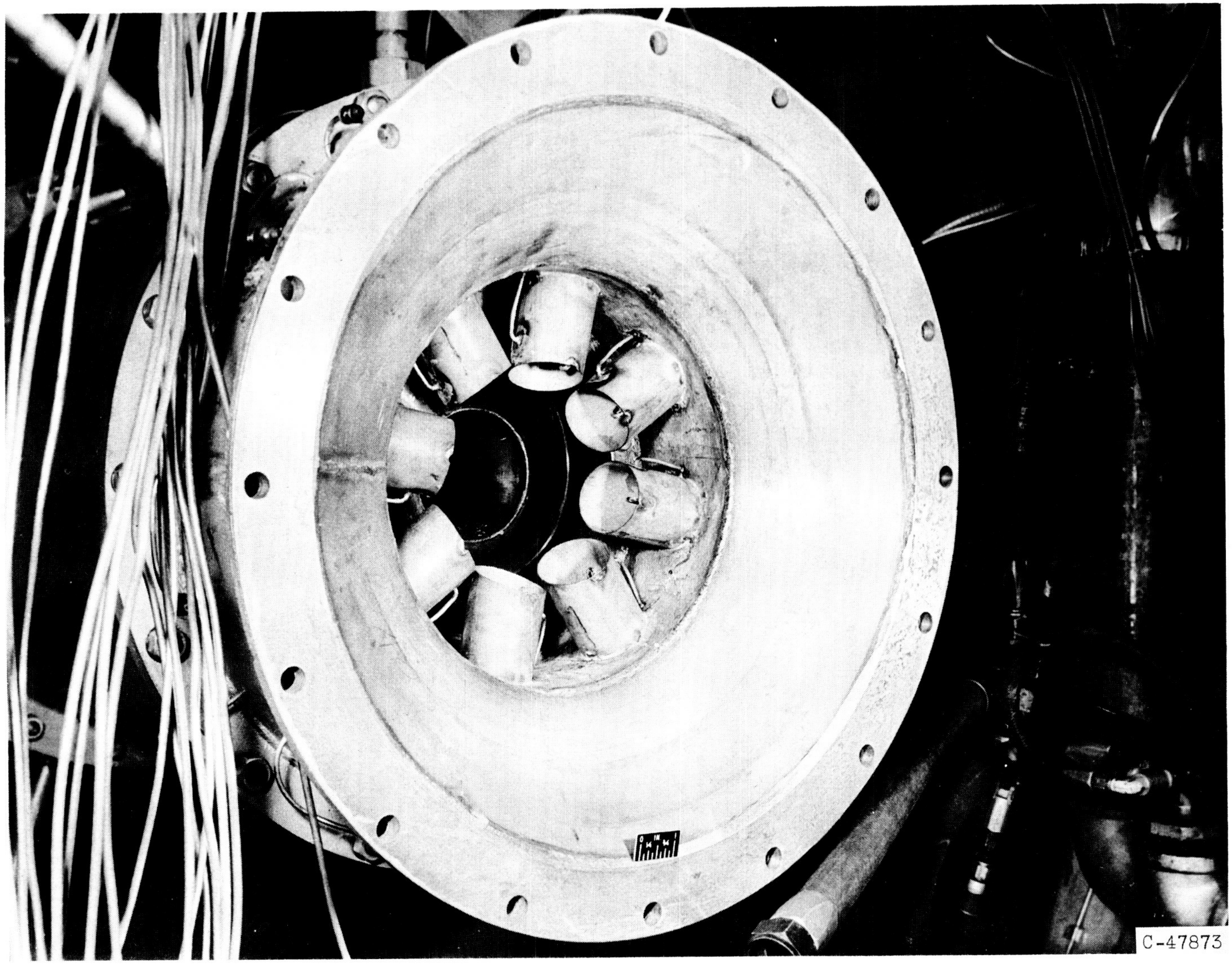


Figure 4. - View of downstream end of radial injection system (configuration III).

E-603

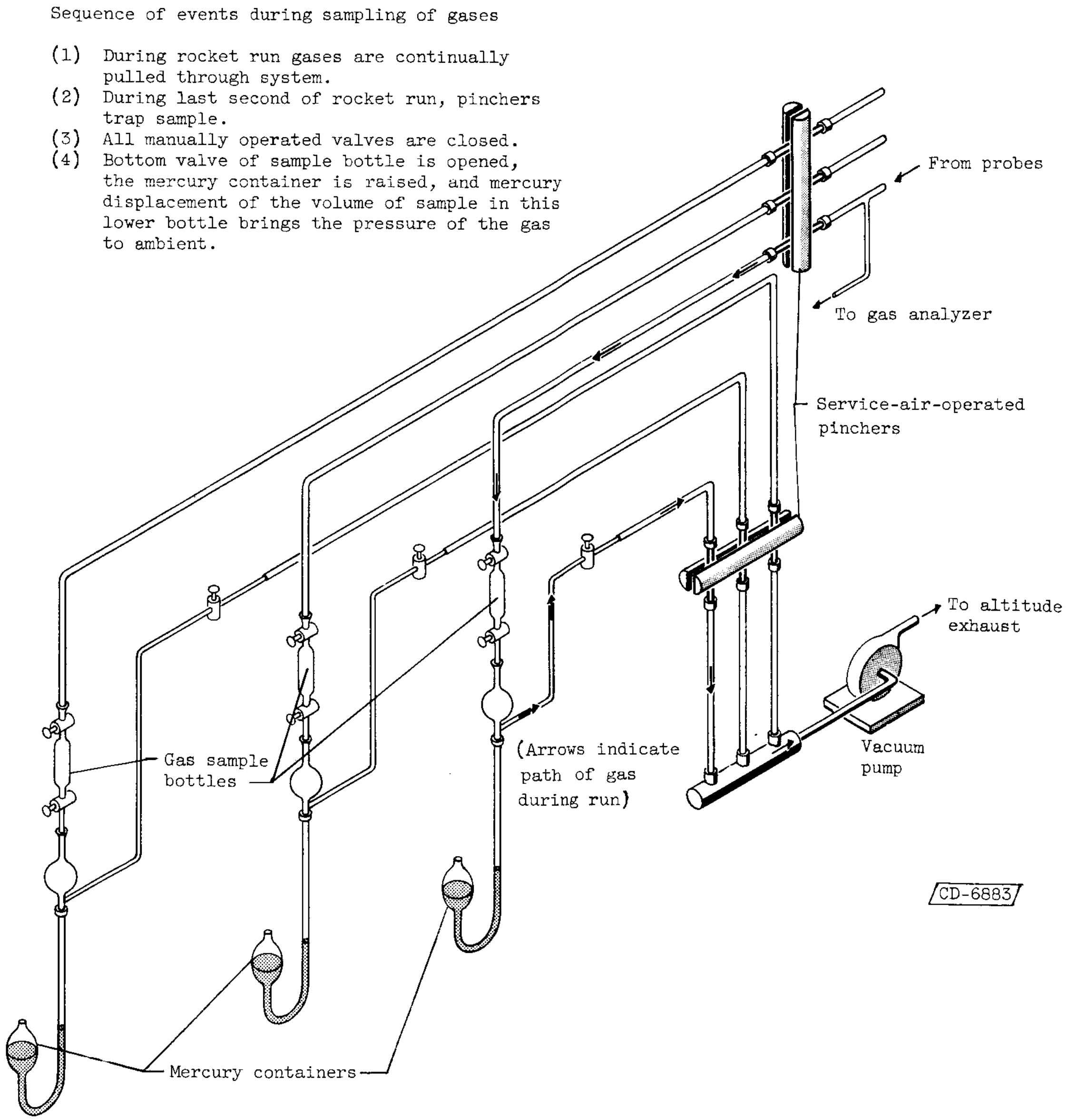
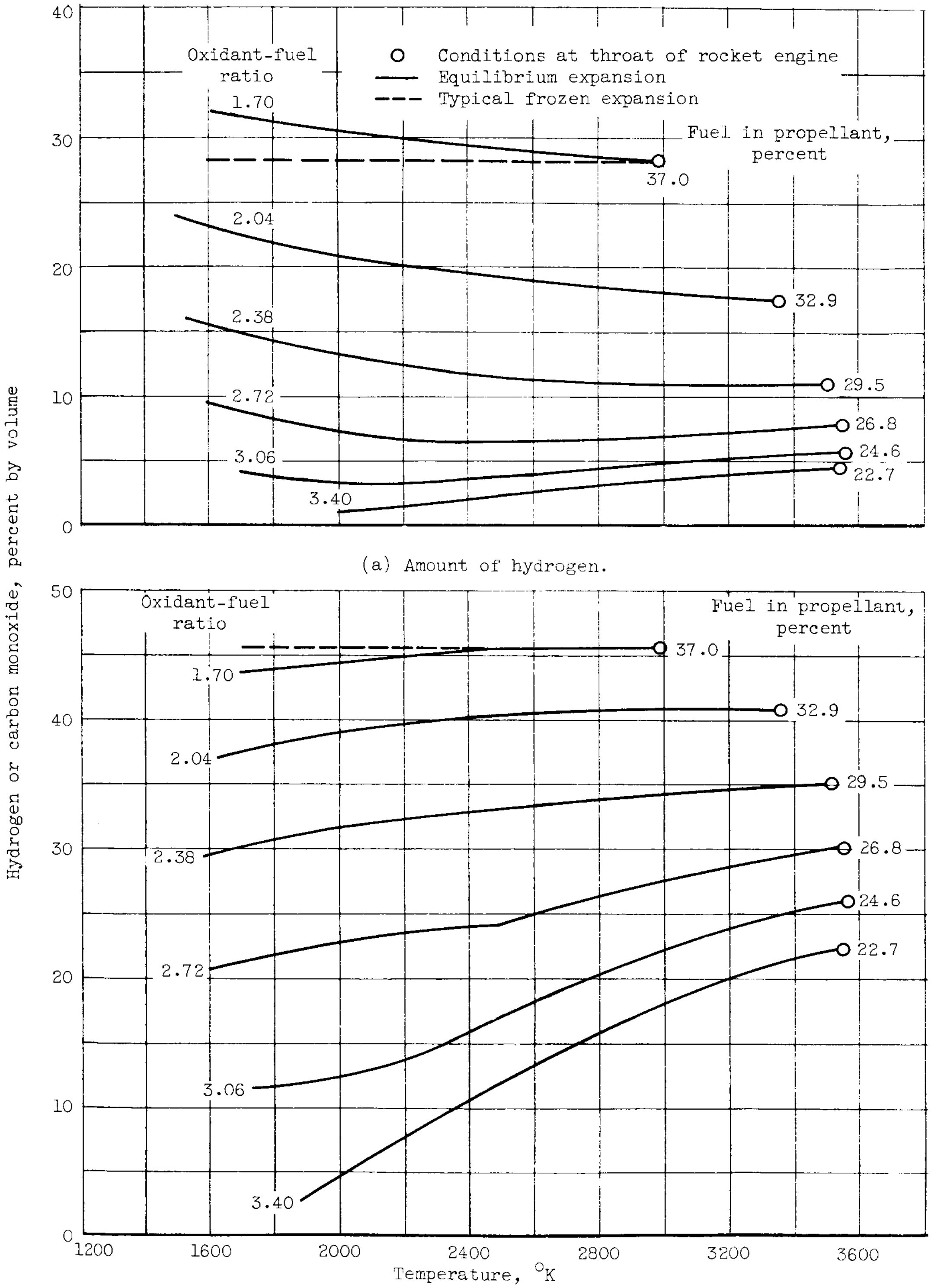


Figure 5. - Schematic drawing of gas sampling system.



(b) Amount of carbon monoxide.

Figure 6. - Variation of theoretical composition of exhaust gases at different temperatures and oxidant-fuel ratios.

E-603

E-603

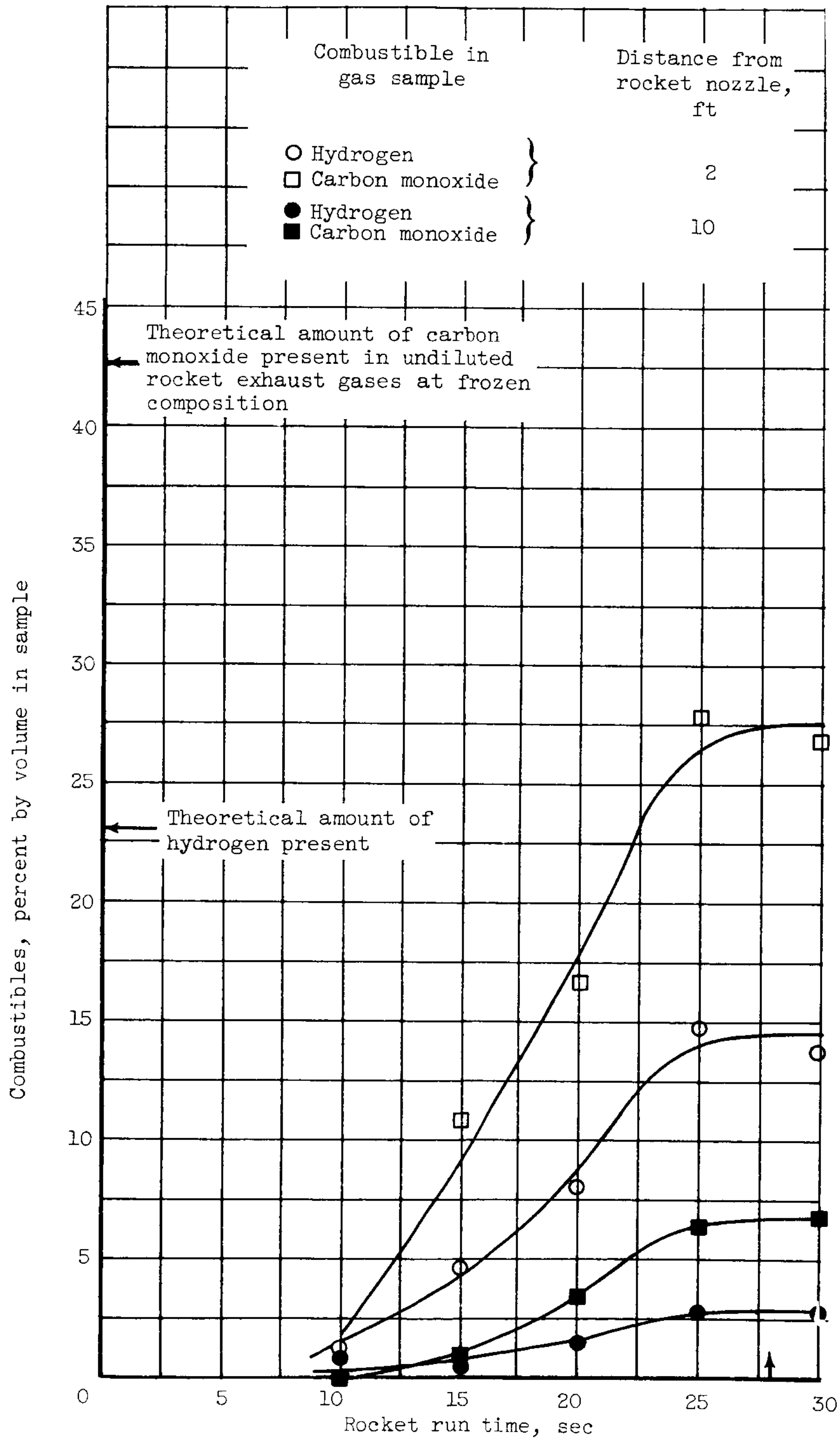


Figure 7. - Method of determining time constant of sampling system. Rocket oxidant-fuel ratio, 1.85; exhaust chamber pressure, 330 pounds per square foot absolute; bypass airflow, 2.3 pounds per second.

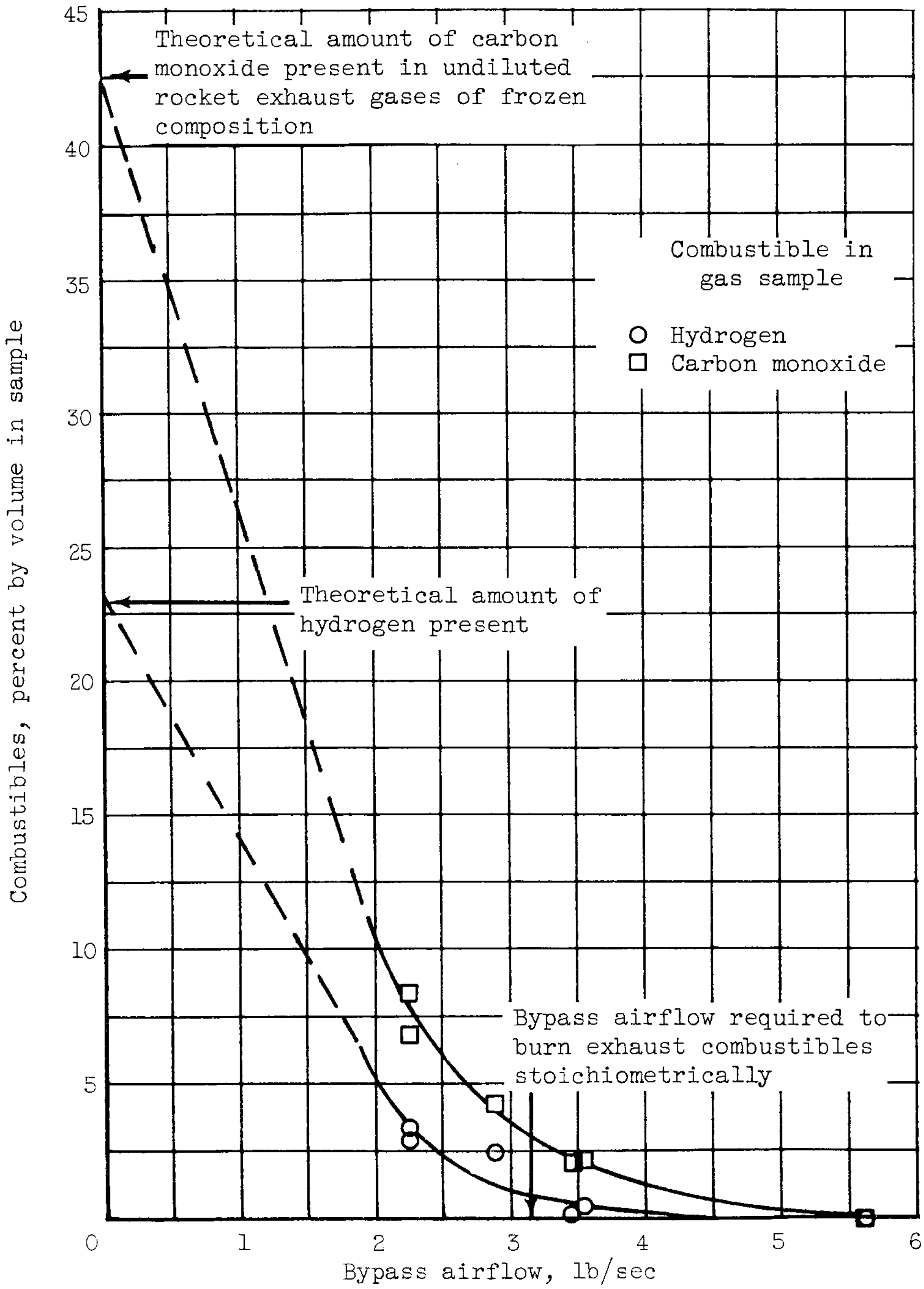


Figure 8. - Variation of percent of combustibles in gas samples with bypass airflow. Rocket oxidant-fuel ratio, 1.85; ambient pressure, approximately 350 pounds per square foot absolute; rocket propellant flow, approximately 1.35 pounds per second. Samples taken 10 feet downstream of rocket nozzle.

E-603

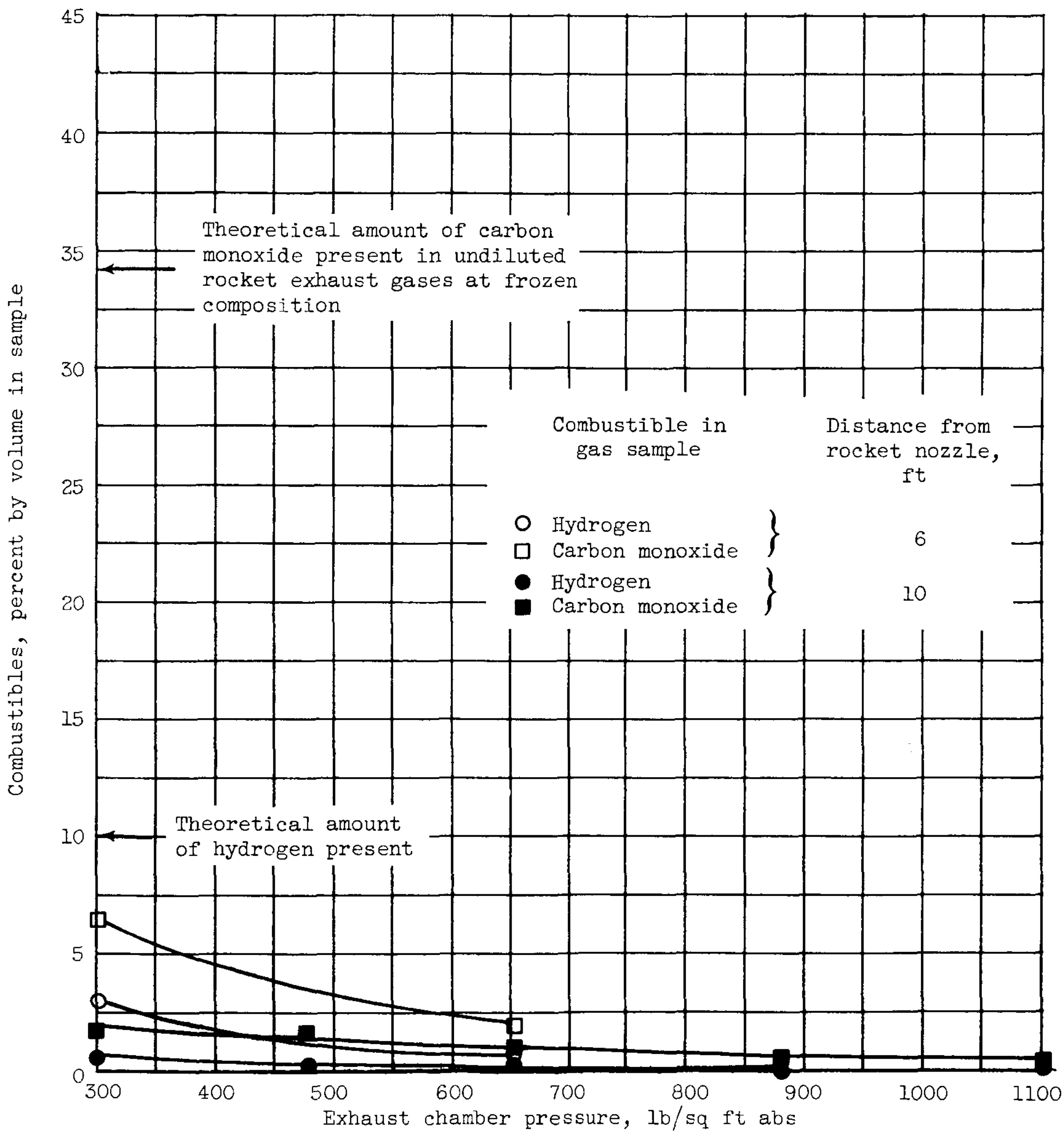
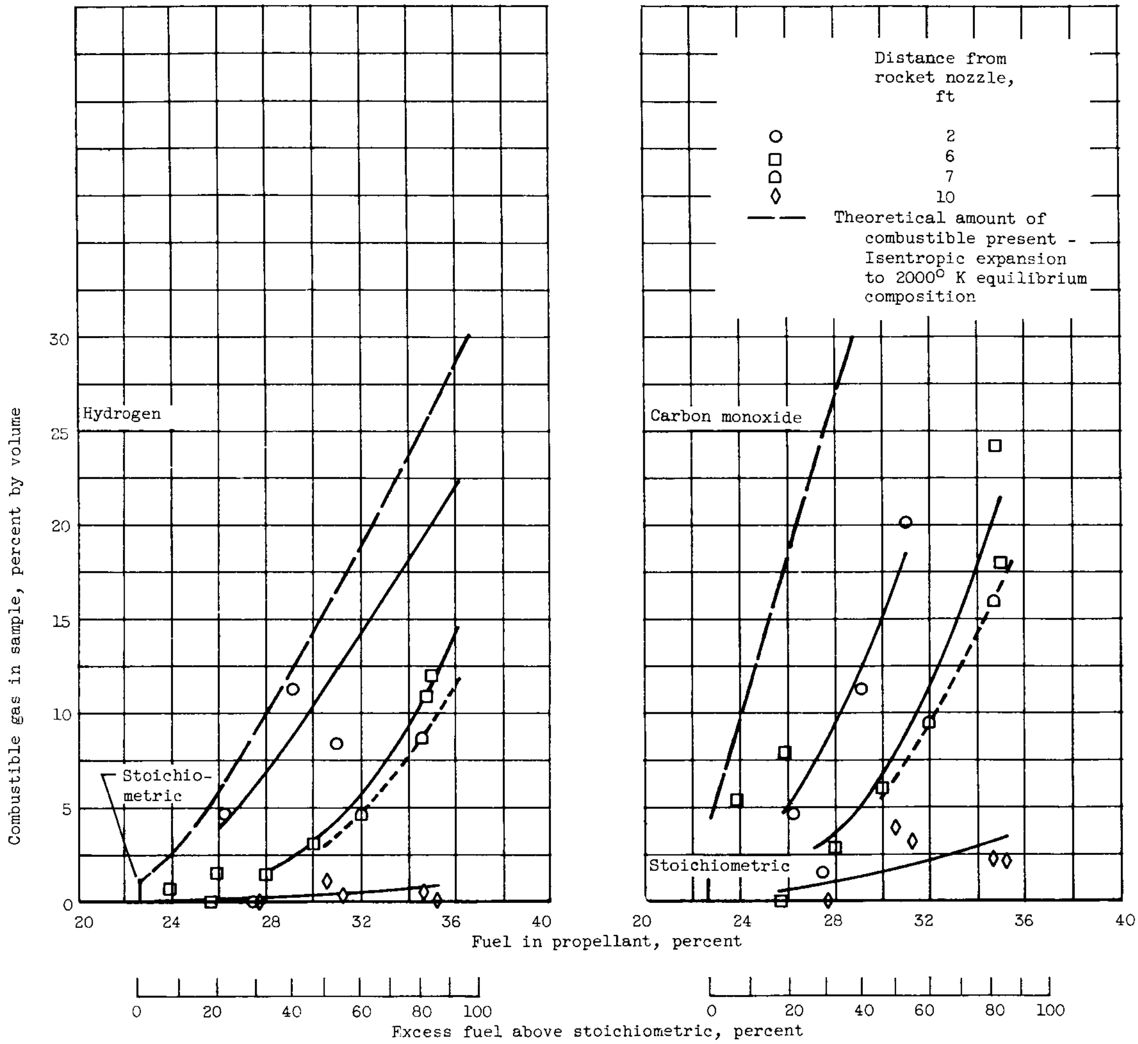


Figure 9. - Variation of percent of combustibles in gas samples with exhaust chamber pressure. Rocket oxidant-fuel ratio, 2.45; bypass airflow, 2.6 pounds per second.

E-603

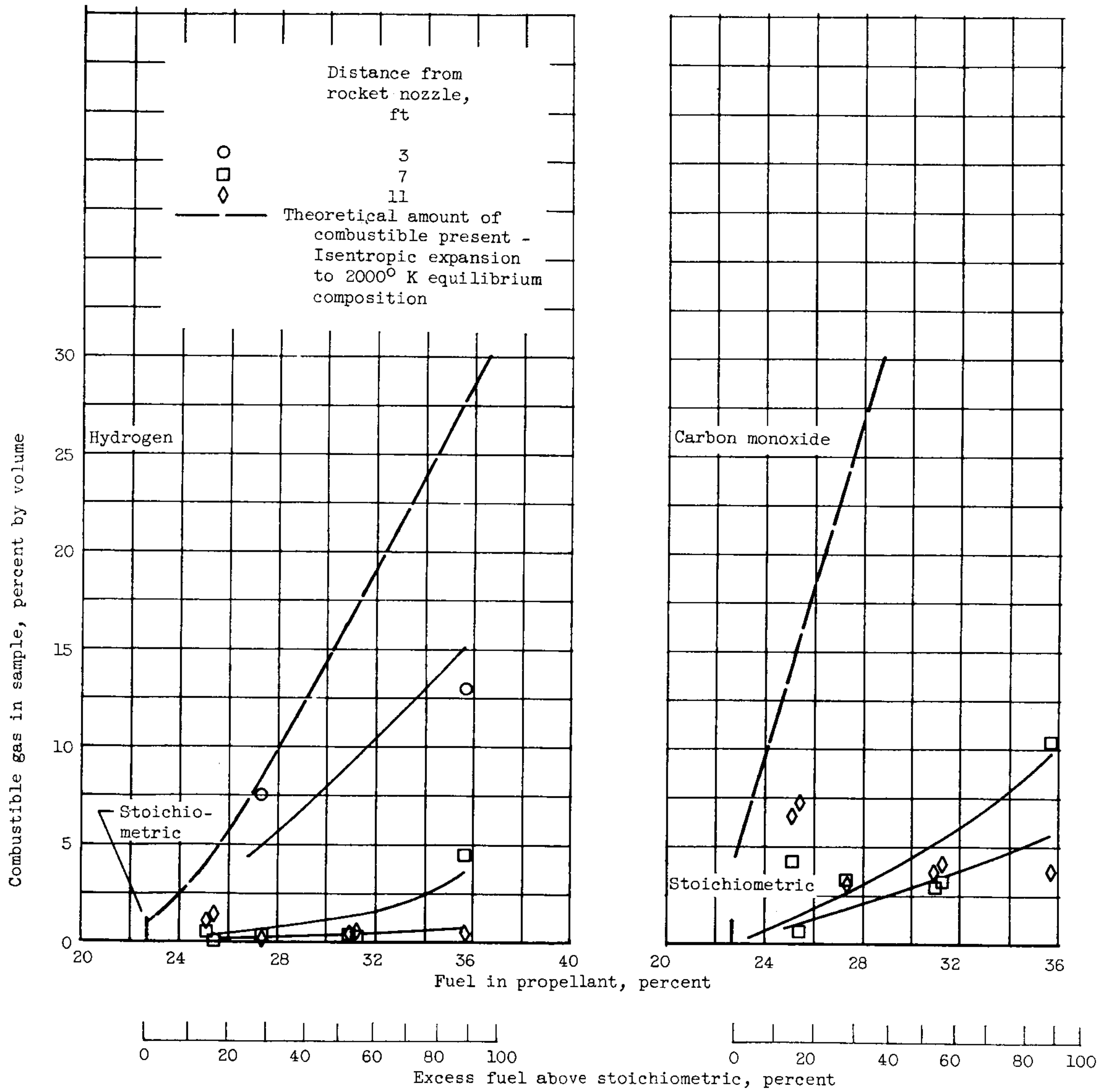


(a) Configuration I.

Figure 10. - Effect of rocket propellant mixture on concentration of combustibles in exhaust at different sampling stations. Average ambient pressure, 350 pounds per square foot absolute. Bypass airflow metered to supply exact amount required to burn combustibles stoichiometrically at each rocket propellant mixture.

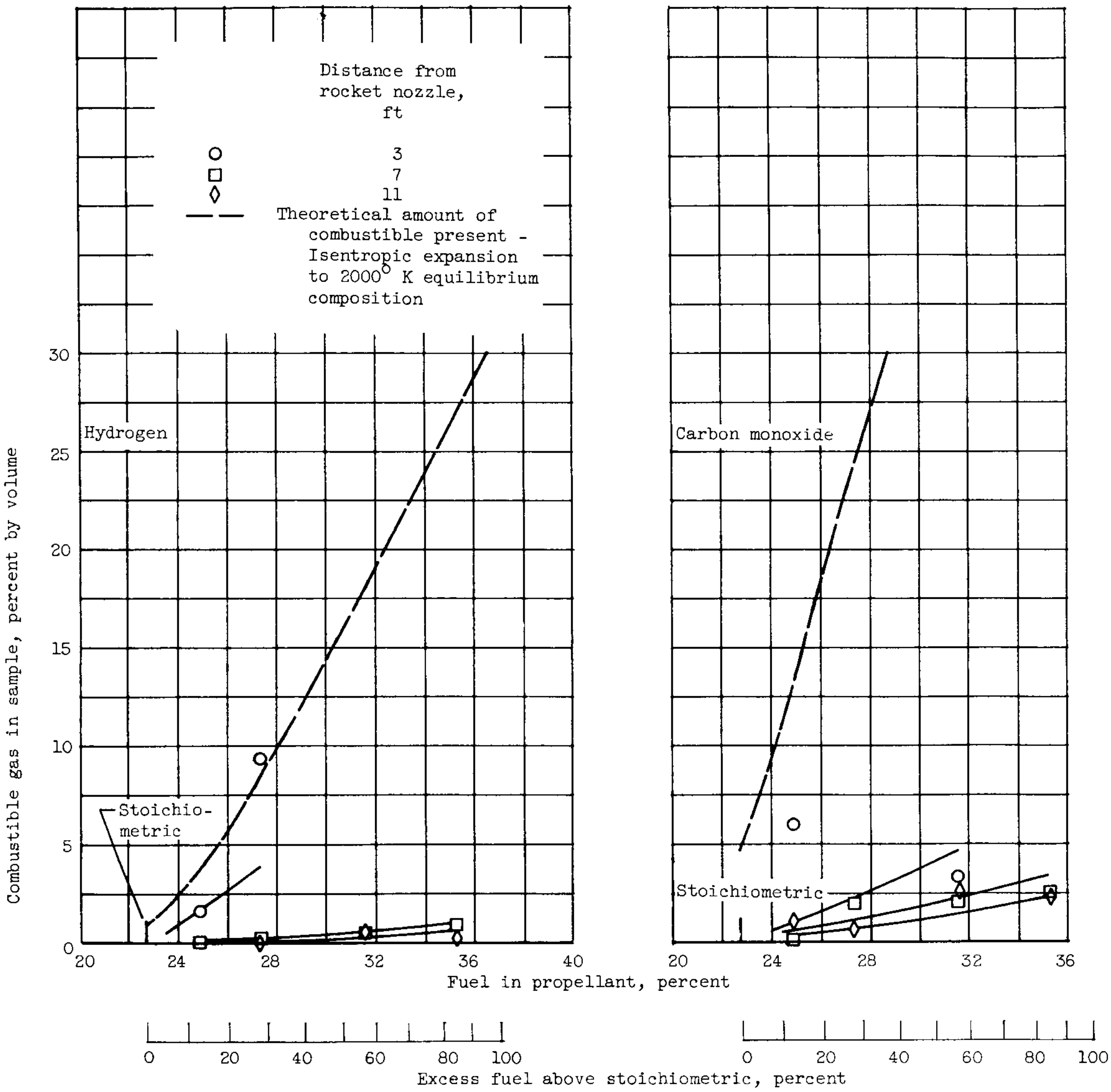
E-603

CH-3 back



(b) Configuration II.

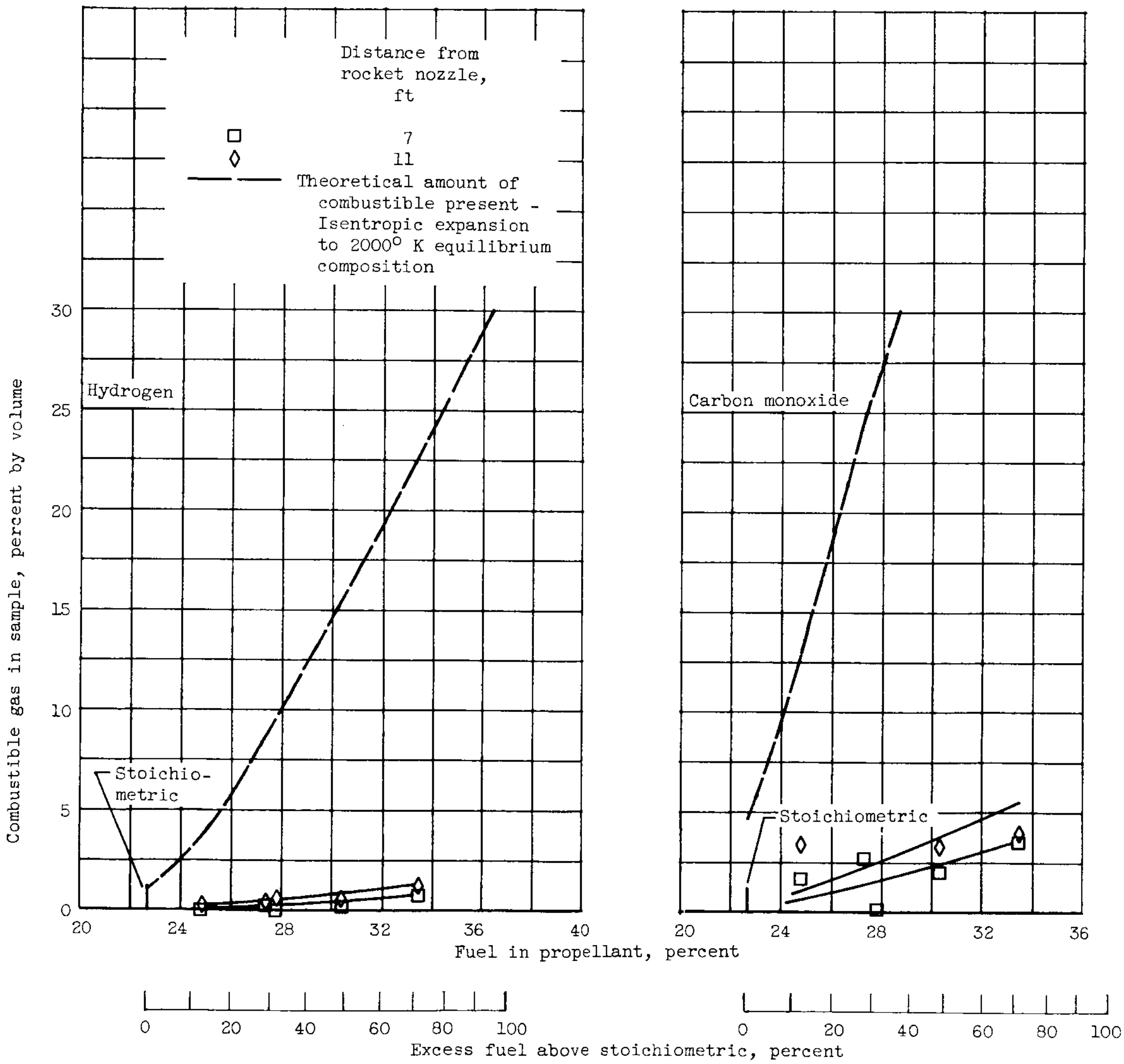
Figure 10. - Continued. Effect of rocket propellant mixture on concentration of combustibles in exhaust at different sampling stations. Average ambient pressure, 350 pounds per square foot absolute. Bypass airflow metered to supply exact amount required to burn combustibles stoichiometrically at each rocket propellant mixture.



(c) Configuration III.

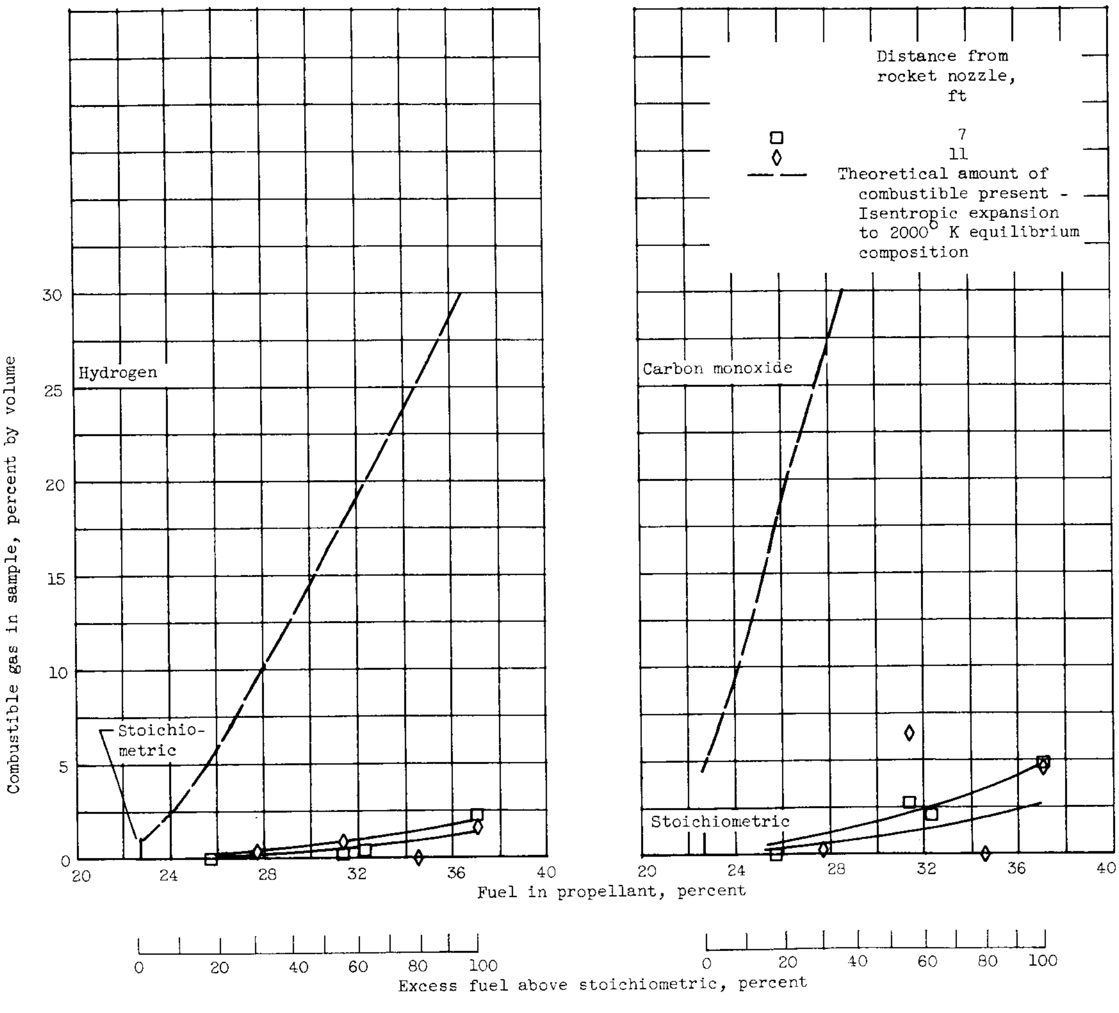
Figure 10. - Continued. Effect of rocket propellant mixture on concentration of combustibles in exhaust at different sampling stations. Average ambient pressure, 350 pounds per square foot absolute. Bypass airflow metered to supply exact amount required to burn combustibles stoichiometrically at each rocket propellant mixture.

E-603



(d) Configuration IV.

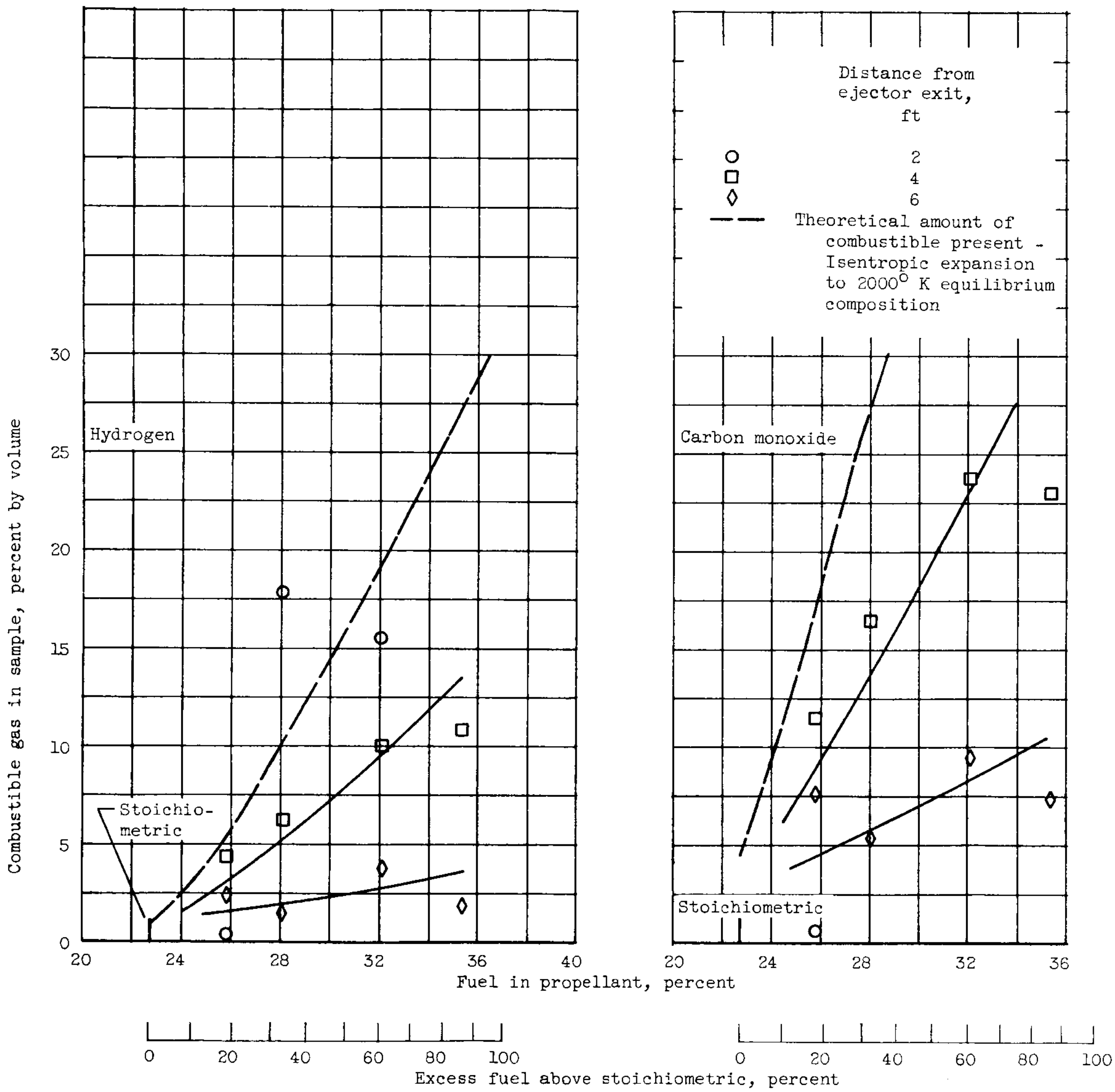
Figure 10. - Continued. Effect of rocket propellant mixture on concentration of combustibles in exhaust at different sampling stations. Average ambient pressure, 350 pounds per square foot absolute. Bypass airflow metered to supply exact amount required to burn combustibles stoichiometrically at each rocket propellant mixture.



(e) Configuration V.

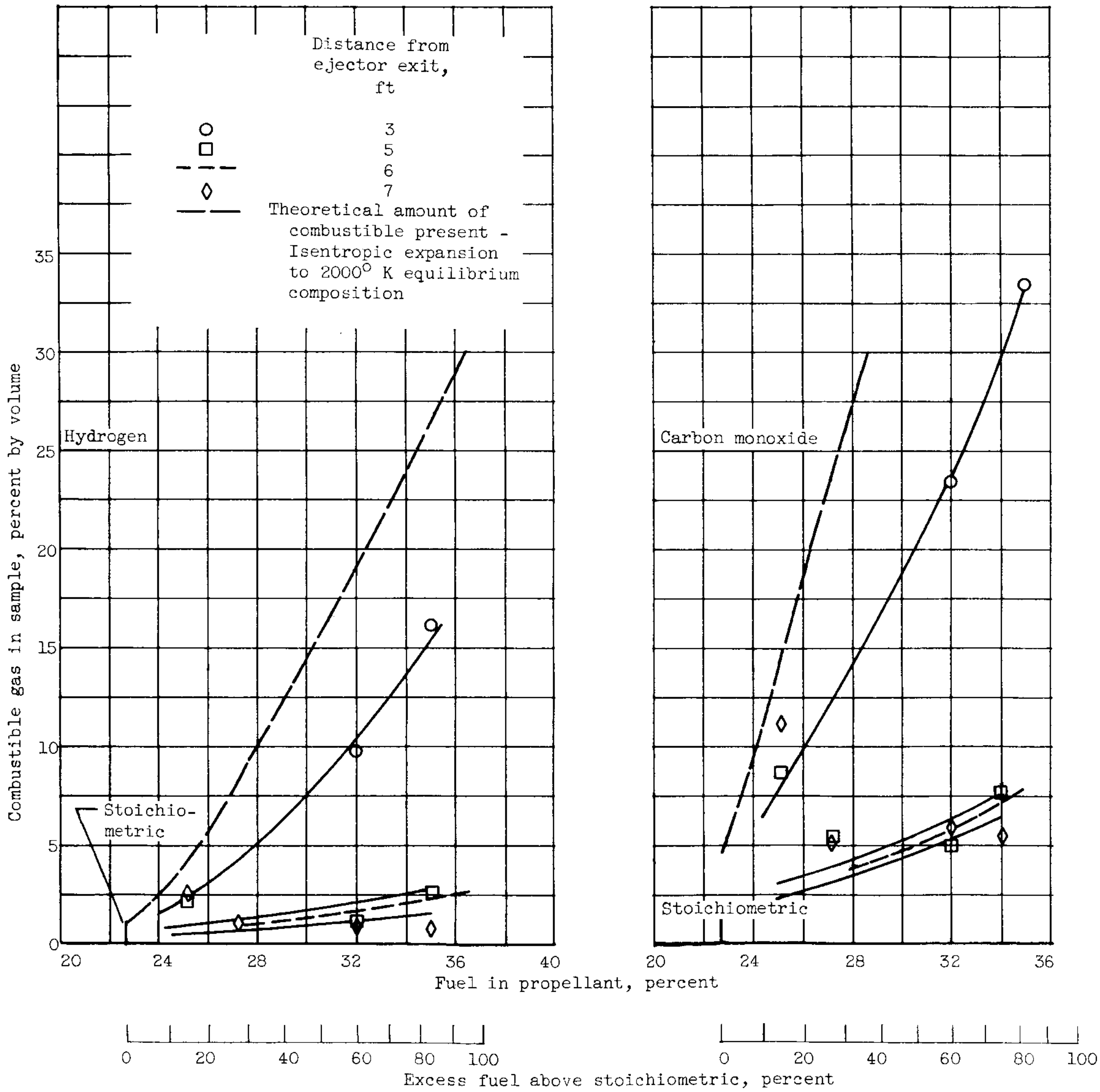
Figure 10. - Continued. Effect of rocket propellant mixture on concentration of combustibles in exhaust at different sampling stations. Average ambient pressure, 350 pounds per square foot absolute. Bypass airflow metered to supply exact amount required to burn combustibles stoichiometrically at each rocket propellant mixture.

E-603



(f) Configuration IE.

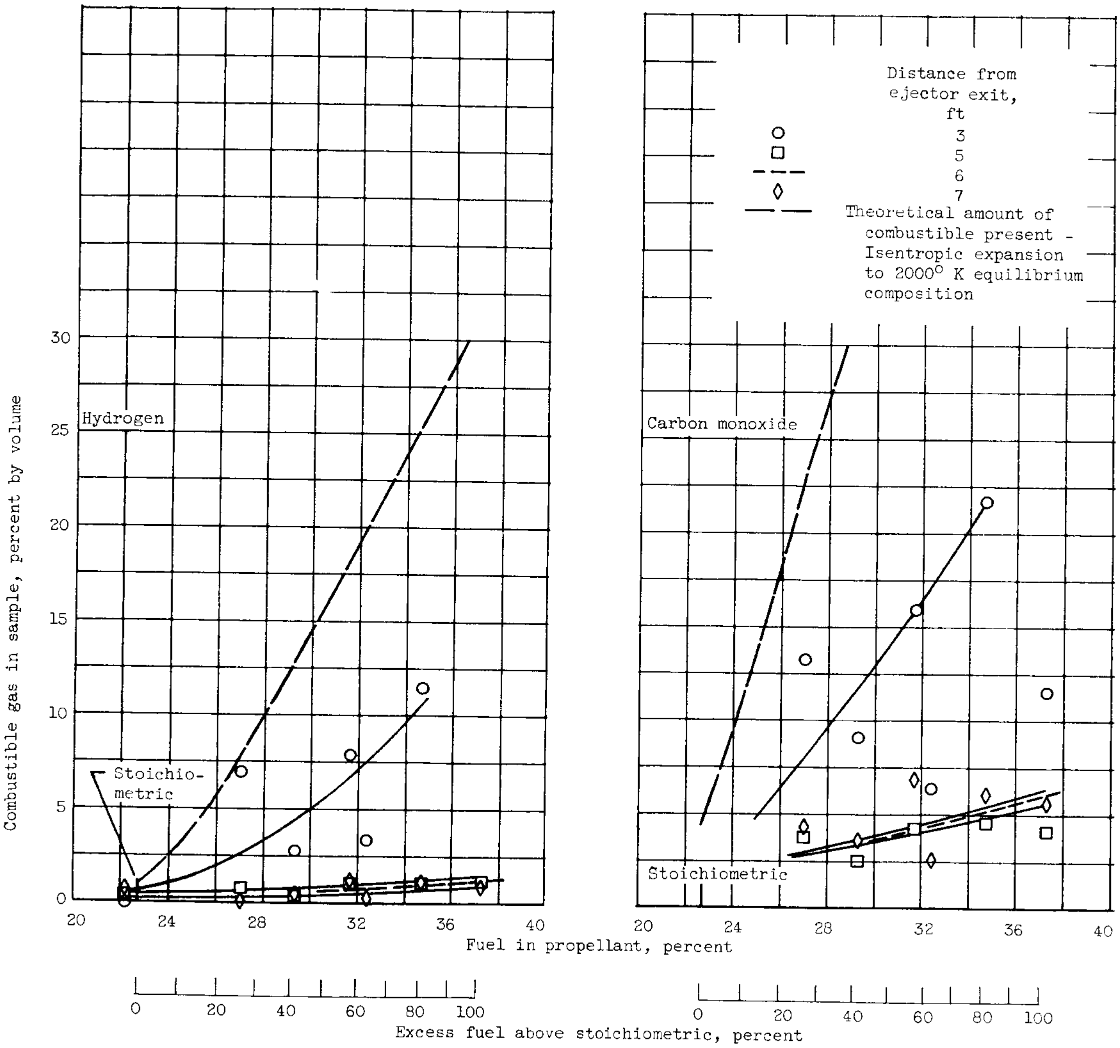
Figure 10. - Continued. Effect of rocket propellant mixture on concentration of combustibles in exhaust at different sampling stations. Average ambient pressure, 350 pounds per square foot absolute. Bypass airflow metered to supply exact amount required to burn combustibles stoichiometrically at each rocket propellant mixture.



(g) Configuration IIE.

Figure 10. - Continued. Effect of rocket propellant mixture on concentration of combustibles in exhaust at different sampling stations. Average ambient pressure, 350 pounds per square foot absolute. Bypass airflow metered to supply exact amount required to burn combustibles stoichiometrically at each rocket propellant mixture.

E-603



(h) Configuration IIIE.

Figure 10. - Concluded. Effect of rocket propellant mixture on concentration of combustibles in exhaust at different sampling stations. Average ambient pressure, 350 pounds per square foot absolute. Bypass airflow metered to supply exact amount required to burn combustibles stoichiometrically at each rocket propellant mixture.